Balancing Middle Earth: Integrating Ecological Sustainability and Effective Research into a Professional Engineering Degree in New Zealand

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Abstract - **Major international assessments have concluded that resource depletion is rampant and society has overshot its ecological capacity. Therefore, education of future generations charged with reversing these trends is essential for environmental sustainability. Engineers impact on biophysical supplies and ensuing wastes so are critical players for ensuring that ecosystems can support current and future civilisations. We report on successful learning outcomes with a professional engineering degree in New Zealand where many assignments relate to real-world problem solving in partnership with nature. These include calculating ecological footprints and core research courses integrated into the community. Students are instructed in the principles of interdependent ecosystems and societies and engage in active learning activities through numerous exercises relating to environmental sustainability throughout their degree. Measures of success are demonstrated and barriers towards effective integration of environmental sustainability in engineering education are highlighted.**

Key Words- ecosystem, research, engineering, New Zealand.

INTRODUCTION

Heightened awareness of unsustainable resource use and damaging ecosystem impacts that overshoot the carrying capacity of our biosphere are reported since the United Nations Conference on the Human Environment [1]. A renowned economics professor and pioneer critic of conventional economics explained that sustainable *growth* is not possible since the economy is an open sub-system of the earth's ecosystem, which is finite, non-growing and materially closed [2]. It is necessary to educate student engineers about the importance of wisely using ecosystem goods and services, alongside technical material, to ensure survival of the interdependent biotic and fiscal economies [3]-[4]. Engineers are instrumental for providing safe and reliable infrastructure that enables civilisations to develop. They are charged with important technical and business decisions on projects which modify natural resource supplies and waste discharges in the environment [5]. Therefore, engineers should be largely represented among responsible managers of the environment in order to sustain the biocapacity of the planet [5]-[9]. This can only happen if they are sufficiently educated about effects on biophysical resources of the environment in which they are working. However, the understanding and value of how to engineer with due consideration for the planet is limited amongst most engineering academics [3], [6]-[9]. Student's knowledge of sustainable engineering practice can be enhanced through real-world research projects aligned to practising engineers that simultaneously nurture their appetite for research.

Accreditation of the Natural Resources Engineering (NRE) degree (internationally recognised by the Washington Accord) is conducted by the Institution of Professional Engineers New Zealand. This degree imparts an underlying principle of integrating ecological sustainability with technical problem-solving and design, by adopting the approach of engineering in partnership with nature. Its philosophy and curriculum are similar to the metadiscipline of sustainability science and engineering and align with the direction of ecological engineering [3]-[4], [10] but is unique in New Zealand [11]. With the current period designated as the 'Decade of Education for Sustainable Development', it is pertinent timing to reassess how we integrate this initiative in our role as educators within the engineering profession. Concurrently, it is beneficial to examine how effectively we align our teaching to the principles and practices adopted by the New Zealand government through implementing Agenda 21 and other sustainable initiatives [12]. We report here on an effective model that integrates ecological sustainability into a professional engineering degree in New Zealand throughout its curriculum. Additionally, we demonstrate the valuable research component of this degree and how its undergraduates have become leaders in interrelated engineering and environmental sustainability activities.

METHODOLOGY

I. Developing a Contextual, Active Learning Approach

Our examination of how best to educate engineers in respect of the context of their actions and the complex connections with the environment in which they will work, began with a brief review of our methods employed for delivering courses. Each engineering course for second and third year students consisted of three hours of lectures a week (for 12 weeks) and 12 hours of tutorial/laboratory contact time during the course. Overall, each second and third year course had an imposed maximum instructor-student contact time of 48 hours. In the fourth year courses, there was an imposed

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maximum instructor-student contact time of 30 lectures and 12 hours for tutorials and/or laboratories. Students were expected to spend up to 120 hours working on each course with a full-time student undertaking ten courses of equal weighting per academic year. Educational research of the learning outcomes from lectures show mixed student and tutor experiences with limited studies reporting memorable or stimulating lectures. Lectures are considered to be passive from the learners' viewpoint [13]-[14] highlighting the transmission aspect with a flow of information from lecturer to student but less emphasis on interaction between lecturer and students or between students themselves [15]-[16]. The structure and materials in lectures fosters students learning for an exam (shallow learning) rather than learning to further their understanding in a subject domain and to stimulate their motivation (deep learning) [16]. Nonetheless, occasions exist where lectures may be the best method of material delivery (i.e. where fundamental laws and theorems are taught).

Concurrently, we examined how students can best develop their understanding within the context of professional natural resources engineering practice. Situated cognition recognises that 'the activity in which knowledge is developed and deployed… is not separable from or ancillary to learning and cognition' [16]. In essence, the *context* in which learning takes place has a strong connection to what is actually learnt. This suggests that most methods and techniques learnt in engineering curricula may actually differ from those undertaken in professional practice, which is especially relevant to natural resources and environmental engineers who practice at the interface of ecosystems [12]. These engineers engage in a highly interdisciplinary workplace, requiring social, environmental and technical competence. Since most of their projects inherently require interacting with communities, clear articulation of a broad environmental knowledge is critical in order to manage effectively their engineering projects.

This review stimulated us to introduce professional practice and real-world problems to students typically learning discrete topics and problems, primarily in lecture situations. It followed from previous propositions by engineering educationalists for enabling students to practice integrated technical, social and environmental skills [6]. This required a shift in problem solving, from discrete knowledge acquisition and understanding towards a solution for real-world problems involving analysis, synthesis and evaluation of the effectiveness of solutions. This shift represents a movement across the hierarchies of the cognitive domain classified by Bloom's educational taxonomy [17]. Therefore, we introduced real-world assignments that fostered active learning in accordance with its pedagogical principles [13]-[14]. Active learning, which lends itself to a more diverse range of learning styles, primarily encouraged students to organise what they needed to know in order to solve the prescribed problem, thus transferring the responsibility for learning to themselves. Students' learning and achievements were improved through active learning approaches reported in other physical sciences [18]. This approach appears to support problem solving in the real-world context, group work as well as personal and peer reflection of the assigned task, approach and resulting outcomes [14].

2. Integrating Active Learning Activities in Assignments

Active learning approaches with assignments incorporating ecological sustainability and research were implemented, mainly in the final two years, in the natural resources engineering curriculum. All courses were co-taught in the initial two years in common with another (civil) engineering degree. Assignments were based on genuine problem solving exercises that enhanced their applicability (Table 1).

In Environmental Quality and Ecosystems (ENNR 203), students were required to draft a hypothetical ecohydrology site assessment as part of an AEE (Assessment of Environmental Effects) for a proposed large residential local development. The scenario given was current, contextual and required systems thinking and reasoning skills. A successful grade required students to interrelate material across the course, particularly identifying the interdependence of ecosystems, hydrology and economic developments. The assignment required a synthesis of content, introduced a real-world engineering problem, provided opportunity for cooperative learning and so fostered active learning not always afforded with more mathematical-focussed problems.

In the NRE degree only, students were required to calculate their net household ecological footprint over ten weeks in Ecological Engineering 1 (ENNR 305). They were provided with a complex spreadsheet which contained (along with guidelines) many quantitative variables from which to assess their impacts including travel, food consumption, household construction and energy use. Because of the substantial duration of this task and the requirement to calculate their *own* footprint, students were empowered to take ownership for their learning (and environmental impact) by active engagement with their peers as well as analysis of their resource consumption and waste generation. In the same course, student teams also pursued a mini research project where they identified, contacted, explored and articulated a different ecological engineering project in New Zealand (Table 1). This assignment aided their ability to integrate material from other courses and further developed group work and cooperative learning.

In Ecological Engineering 2 (ENNR 405), students had to identify natural capital from anthropogenic waste streams in the New Zealand context. They researched different waste streams and provided technically feasible solutions to the prescribed problem. This exercise required an integration of ecological sustainability and the goal of developing engineering solutions in partnership with ecosystems. These NRE students also became more deeply engaged with sustainable engineering in the project course (ENNR 429) aligned with practising engineers. Projects were designed as real-world problems integrated into the local community with a premise of sustainable development where interdependencies between people, the environment and the economy were addressed concomitant to technical solutions.

Assignment themes in these NRE (ENNR coded) courses provided a structured approach for integrating real-world problems through group work, while concurrently fostering students' motivation and reasoning skills through active learning approaches.

TABLE 1

ASSIGNMENTS RELATING TO ECOLOGICAL SUSTAINABILITY WITH RESEARCH COMPONENTS ACROSS THE NRE CURRICULUM

Course Code	Assignment weight (%)		Primary Objectives
ENNR 203:		Name	**ENVIRONMENTAL QUALITY AND ECOSYSTEMS**
	7.5	Task	Mock Assessment of Environmental Effects (AEE) integrating material of interdependent ecohydrology and engineering:
			Integrate interdisciplinary theory and its application in professional engineering into an 'advisory' report
			Develop technical writing and coupled environmental, technical and social reasoning skills
ENNR 305:		Name	**ECOLOGICAL ENGINEERING 1**
	10	Task	Calculate net household ecological footprint on earth's resources in global hectares using standardised accounting:
			Advance systems thinking and ability to critique interdisciplinary published material
			Develop deeper understanding of pertinent ecosystem dynamics that sustain human developments
ENNR 305:	30	Task	Research established ecological engineering project in New Zealand:
			Contact primary stakeholders involved with chosen project
			Collate existing maps, engineering designs, plans and reports associated with the project
			Comprehend ecological engineering as distinct from other engineering and logistics of implementing such projects
			Develop a portfolio of outputs including technical engineering report, work plan and public relations webpage/poster
ENNR 405:		Name	**ECOLOGICAL ENGINEERING 2**
	40	Task	Detailed technical plan for converting waste streams into natural capital commodities:
			Design sustainable and integrated treatment technologies based on the balanced use of ecosystems
			Experience real-world problem-solving for complex wastes in New Zealand context
			Develop entrepreneurial skills by creative problem solving and assess value through ecological accounting practices
ENNR 429:		Name	**RESEARCH PROJECT IN NATURAL RESOURCES ENGINEERING** (2 course weighting)
	100	Task	Engage in real-world problem solving through research aligned to external industry or regulatory authorities:
			Develop detailed and quality assured methodology for conducting a rigorous (team-based) research project
			Generate a detailed budget, timeline and project management strategy for proposed research
			Write a mini research proposal examined by programme academics
			Generate, collate and critique data for a defined problem. Perform necessary statistical analyses/modelling
			Design a sustainable solution for the defined problem incorporating triple-bottom line considerations
			Produce sound conclusions and substantial literature review for specific project goals
			Deliver final technical report, oral presentation and poster to academics and external parties

RESULTS AND DISCUSSION

Measures of success of our objectives were based on assignment grades, course GPAs, course surveys and others including achievements by students engaged in active undergraduate research. Courses reported here were recently developed so only data for 2005-2006 are available. Student numbers in ENNR 203 included those from other engineering programmes (but we could not distinguish grades between programmes) while all other ENNR courses with smaller enrolments included only the NRE students.

Some students struggled with the ecohydrology assignment in ENNR 203 which may be due to numerous reasons. It (a) was not calculation-based, (b) required systems analysis and reasoning skills and (c) was the first year that a relatively complex task was assigned, albeit with detailed prescriptions and tutorials. Only 2% (4 out of 182 students) received the full 7.5 marks for this assignment, while the majority received between 4.5 and 5.5 marks (Figure 1). At least 12 (7%) students did not submit assignments so were awarded zero marks. Marks presented reflect any penalty imposed of 1 mark per day if the assignment was submitted late. Students appeared to struggle with integrating systems thinking and sustainable concepts early in their engineering degree. However, some (22 out of the 182) students excelled at this achieving a mark of between 6.5 and 7.5. They clearly articulated and integrated material they learnt across the course, which required quite a bit of reasoning skills of the interdependence of construction developments and ecosystems (i.e. not just regurgitated lecture material), thus reflecting their knowledge of the interdependence of our biotic and fiscal economies.

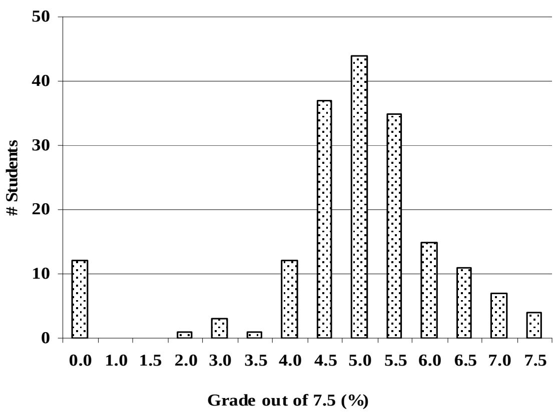

FIGURE I

MARKS FOR ECOHYDROLOGY ASSIGNMENT (ENNR 203) IN 2006

In ENNR 305, students conducted the ecological footprint assignment individually (n=10) in 2005 and in teams (n=23) in 2006, primarily due to a significant increase in student numbers (and lack of appropriate tutors to assist with correcting) in 2006. No student received full marks for the assignment. Two students in 2005 received a grade of 8.5 out of 10 while another two received a grade of 8 (Figure 2). In 2006, four of the students (17%) received 8/10 for this assignment, while most (n=15) of the class received between 7 and 7.6/10. These marks are relatively high compared with similar challenging assignments in other courses for these students. This may be due to the active learning approach facilitated through a real-world exercise that motivated these students (see Figure 3 later on). Most students performed better in 2006 than in 2005, which may be attributed to a number of things. The assignment was provided as an individual exercise in 2005 but performed a team effort in

2006. It is possible that motivation and synergy from team efforts resulted in better assignments, which correlates with the belief of constructivist learning [13]. This assignment was only introduced in 2005, and its structure and instruction was improved for 2006 resulting from reflective critiquing.

In ENNR 305, marks received for the mini research team projects were individually weighted according to anonymous peer marking in 2006 (ratio total:average peer individual marks allocated*instructor team mark) but this weighting was not applied in 2005. Therefore, each team member received the same project mark in 2005 but not necessarily the same in 2006. There was minimal grade variation across the class for this assignment in 2005 as students received between 21 and 26 out of 30 (Figure 2). This may be attributed to the absence of weighting applied to team marks coupled with lower enrolments. In 2006, results were more variable with one team achieving excellent scores (27 to 29 out of 30) but other teams were not as strong, as most students achieved a grade of between 17 and 24 (mean of 20±5). An outlier in this range was a student who received 10 out of 30 for the project while their team members received 18 or 19. The student who received 10 contributed little to the project and did not deliver on the allocated tasks they assumed responsibility for (and so ultimately failed the course). Each team allocated specific tasks to its members in order to track who was responsible for each part of the project. This strategy empowered students to take responsibility for and manage their own learning through active interaction. This course was one of four for the NRE degree that was not taught in conjunction with other larger (in student numbers) courses from the civil engineering degree programme and so afforded greater teacher-student interactive learning, which may have assisted student motivation for active learning.

In Ecological Engineering 2 (ENNR 405) in 2006 (the first year of its development), students were required to generate a technical report encompassing triple-bottom line strategies in New Zealand (economic, environmental and social interrelationships) for specific waste streams. They liased with a national company to investigate engineering,

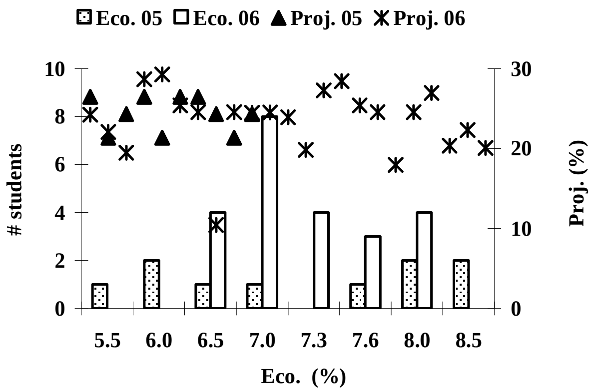

FIGURE 2

MARKS FOR ASSIGNMENTS IN ENNR 305. X-AXIS IS MARKS (OUT OF 10) FOR THE ECOLOGICAL FOOTPRINT CALCULATION. THE PRIMARY Y-AXIS ON THE LHS IS NUMBER OF STUDENTS WHILE THE SECONDARY Y-AXIS ON THE RHS IS MARKS (OUT OF 30) FOR THE PROJECT ASSIGNMENT. ECO. 05 AND ECO. 06 ARE ECOLOGICAL FOOTPRINT CALCULATION 2005 AND 2006, RESPECTIVELY, WHILE PROJ. 05 AND PROJ. 06 ARE MARKS FOR THE MINI RESEARCH PROJECTS IN 2005 AND 2006, RESPECTIVELY. N = 10 (2005) AND N = 23 (2006).

TABLE 2

WASTE TO COMMODITIES RESEARCH PROJECTS IN ENNR 405

Chosen 'waste' stream	Proposed 'commodity' equivalent
Waste glass cullet	Aggregate in permeable paving systems
Greywater	On-site irrigation
Dairy shed wash-down	Fertigation (fertiliser as irrigation)
Base metal mine tailings	Pavement and pre-cast concrete fill
Municipal organic wastes	Topsoil for landscaping and erosion control
Tannery fats	Biodiesel
Roof rainwater	Recirulated water for toilets and irrigation

commercial and ecological knowledge required to demonstrate if their 'waste' was in fact a 'commodity' and were required to produce a mini cost-benefit strategy using both conventional and ecological economics (for which they received a small amount of instruction in these sub-disciplines of economics). Some excellent solutions (for liquid and solid waste streams from various processing plants) were proposed by students that integrated technical feasibility and ecological sustainability (Table 2). The assignment empowered students to think creatively in pursuing alternative yet realistic and cost-effective methods for waste reuse and aligned well with the principles of using ecology to steer technology for sustainable development. A related approach in engineering curricula is reported elsewhere in New Zealand [7].

In the year-long research project course (ENNR 429), students embarked on individual projects in 2005 and 2006 but in teams of three in 2007. The impetus for moving towards group projects was primarily due to a restriction of available supervisors as enrolments increased (from 10 in 2005 to 18 in 2007) but also to recognising the synergy derived from team efforts observed in other courses. Projects were integrated into the community making them real-world challenges and most successfully achieved commitment for costs to be met by their external (non-academic) mentor (Table 3). Students were assessed in this course based on written and oral assignments by a team of academic supervisors. Assessments comprised a project proposal including realistic budgets and timeframes (10%), mid year (20%) and final (50%) comprehensive reports, a poster portfolio (10%) and an abstract summary and oral presentation (10%). All assignments were team efforts but each team allocated specific tasks to its members, while overall course marks were weighted according to quantitative peer feedback (described earlier for ENNR 305) conducted twice during the course. This model proved an effective way for students to take responsibility for budgeting and delivering work on time, which is critical in engineering practice. It also facilitated the opportunity to integrate material learnt throughout their four-year degree and learn complementary skills from the external mentors.

The scope of these projects has been wide reflecting the nature of the NRE degree. Topical issues such as stormwater management, renewable energy technologies and erosion control methods featured prominently in the choice of projects – all of which had a core objective of providing effective solutions by integrating ecological, economic and societal considerations in their technical challenge. Additionally, this course demonstrated social cognition within a real-world problem solving context, a skill not typically taught to engineering students in a lecture setting

TABLE 3
SELECTION OF SOME OF THE REAL-WORLD UNDERGRADUATE RESEARCH PROJECTS (ENNR 429) 2005-2007

Year	Project Title	External Mentor(s)
2007	Quantifying stormwater inputs for resource consent renewal and treatment devises	Local consultancy and councils
	Long-term management of Christchurch City Biosolids	Local city council
	Modelling debris flow in New Zealand catchments via non-dimensionless analysis	National geological research institute
	Design and development of an improved stormwater system in Kaikoura township	Local consultancy and council
	Solar panel design	Local renewable energy consulting company
2006	Soil erosion control on Banks Peninsula, Canterbury: a bioengineering approach	Local city council
	Primary school classroom energy audit	Local primary school, Electricity commission
	Sediment and acidity control at an active coal mine using waste capping materials	Largest national coal company
2005	Applications and treatment efficacy of an urban stormwater infiltration basin	Local consultancy and councils
	Wastewater high rate algae pond: production for biofuel	Local recycling specialists
	The use of coal seam gas waters in New Zealand to treat acid mine drainage	Largest national coal company
	Energy efficiency at the Fonterra Brightwater plant	Largest national dairy foods producer
	The use of green waste compost as a steep slope stabiliser	National water research institute
	Design of an optical sensor for the monitoring of sediment transport in rivers	National landcare research institute

Student Feedback

University anonymous course surveys conducted for ENNR 305 in 2005 and ENNR 405 in 2006 included five questions; how well (i) the course was organised; (ii) the student's interest was stimulated; (iii) the workload compared to other courses; (iv) the level of difficulty compared to other courses and; (v) the opportunity to engage in research-related activities was provided. Clearly, both ENNR 305 and ENNR 405 scored well above the college of engineering mean scores in terms of course organisation, interest and research, while the workload level and level of difficulty did not differ much from college means (Figure 3). These two courses included a significant focus on ecological sustainability in engineering activities, which is not typically emphasised in their other courses co-taught with civil engineering and may explain the elevated students' interest. The NRE degree focuses on imparting an underlying philosophy of working in partnership with nature and students attracted to and enrolled in this degree typically have a strong commitment to environmental sustainability. This is apparent in surveys run by the departmental and college public relations committees, whose results are striking in this regard of motivation for choosing NRE compared to other engineering degrees. It is also possible that their interest was stimulated through active learning encouraged in these courses, outlined earlier. Students rated the research component in these courses to be substantial by comparison to other engineering courses. Incorporating research activities into teaching exposes students early on to the benefits, excitement and relevance of research and seems to engage them during lectures. These results validate our beliefs that integrating research into teaching is effective learning and aligns with the strategic objective of our University to enrol more graduate students by nurturing undergraduates' appreciation and appetite for research. Limited comments were provided by students on these standard questionnaires but generally reflected a high level of motivation and an appreciation of the interdisciplinary material and interactive learning facilitated by smaller class sizes (compared to their other courses). Additionally, students offered positive comments relating to the research component. Anecdotal feedback included 'Research project very helpful for learning', 'Smaller class size facilitated better learning', 'Large amounts of topics of good interest' and 'Beneficial to learn the research shells'.

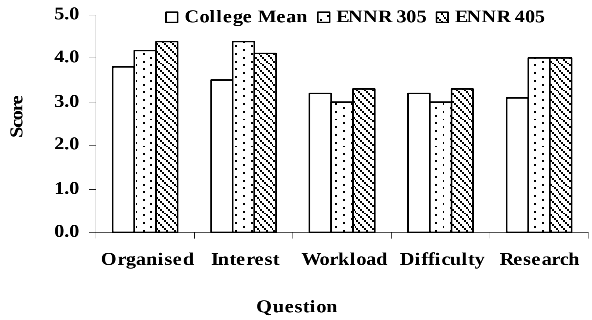

FIGURE 3
COURSE SCORES FOR ENNR 305 IN 2005 AND ENNR 405 IN 2006

Comparison with Other non-NRE Courses

Grade Point Averages (GPA) for NRE (ENNR-coded) courses were compared with other departmental courses taken by these students and with overall engineering means. A higher GPA for ENNR 305 was achieved compared to other 3rd year (300-level) courses in the department or college (Figure 4). This may be due to the increased student interest and motivation in this course, perhaps resulting from the ecological sustainability material and active learning fostered through real-world assignments. Similarly, ENNR 405 and ENNR 429 had higher GPAs compared to the college and department means in 2006. Since ENNR 405 actively engaged students with ecological systems and sustainable engineering through real-world problem-solving, it is likely that they were highly motivated in this course as it aligned with the core philosophy of their degree. In 2005, ENNR 429 had a GPA of 0.13 units greater than the department mean but 0.52 units greater than the college mean. A higher GPA in the project course may have been due to the degree of constructive and iterative feedback from academic and external mentors, which enhanced student learning. Additionally, students chose the project they engaged in and were ultimately interested in its focus so exhibited a high level of ownership and motivation for performing well. It is also likely that students enjoyed the research component where they had the opportunity to integrate material they learnt throughout their four-year engineering degree. Furthermore, anecdotal feedback indicated that a real-world engineering challenge stimulated student interest, which probably translated into a good GPA.

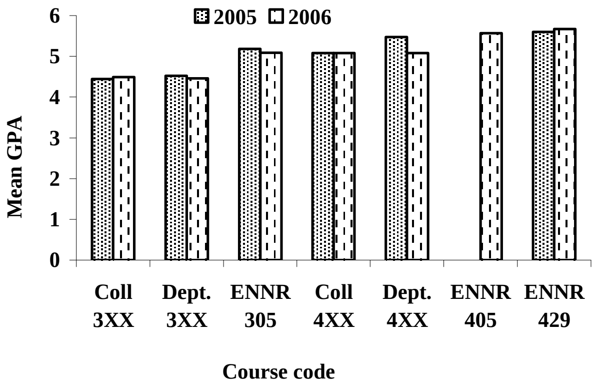

FIGURE 4
MEAN GPA FOR COLLEGE OF ENGINEERING (COLL3XX AND COLL 4XX), CIVIL ENGINEERING DEPARTMENT (DEPT 3XX AND DEPT 4XX) AND NATURAL RESOURCES ENGINEERING (ENNR-CODED) COURSES 2005-2006

Other measures of success from educating effectively our engineering students about ecological sustainability and the value of research are anecdotal but warranted mentioning. Since 2006, these NRE students have been awarded competitive funded fellowships to represent New Zealand at overseas workshops to (i) develop creative and practical solutions for addressing sustainable development; and (ii) contribute new perspectives on engineering research and the challenges of gender issues in engineering. We believe this subset of engineering students is well prepared for assuming the challenge of sustainable engineering given their deeper understanding of ecosystems.

In New Zealand, the professional engineering institution has recently provided guidelines on sustainable engineering but there is limited instruction of integrated environmental sustainability and technical engineering in tertiary education [7], [13]. This may result from a lack of understanding and value of the earth's biocapacity by engineering academics [3], [6]-[8], [23]. While some believe that the planet's capacity to absorb our wastes and provide raw materials and energy is limited [24], others believe that technology can develop fast enough to compensate for society's impact, which may explain the absence of ecological instruction in most engineering curricula. A useful model for explaining the intangible concept of sustainability to engineering students is to adopt ecosystems. Ecosystems support life, are adaptive, recycle chemicals and generate energy and biomass from the sun and so are sustainable. This approach has been valuable in our teaching of the NRE degree so engineering students can better appreciate the components, relationships, dynamics and thus relevance of the living systems that engineering practice impacts and relies upon. A major challenge for tertiary institutions is to demonstrate to potential students concerned with solving environmental and societal problems that engineering has environmental relevance and social value - something that resonates with women and other minorities in particular [8]. This in itself leads to a lack of diversity in engineering, which is a well documented problem [8], [23].

CONCLUSIONS

Major international assessments deduced that civilisations have overshot their ecosystems capacity to ensure the development and survival of future generations. Engineers are pivotal for leading sustainable development for which they require a genuine understanding of ecosystems. The natural resources engineering degree integrates ecological sustainability and engineering in its formation through active learning, engaging with real-world problem solving and research. Students are motivated towards maintaining New Zealand's natural capital leading to a sustainable future.

ACKNOWLEDGMENT

We acknowledge immense support from David Painter, Tom Cochrane and Alison Holmes. www.nre.canterbury.ac.nz

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